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VARIATIONS OF

STUDY OF THE EFFECT OF LOCAL GEOPHYSICAL PHENOMENA ON DIFFERENCES BETWEEN LATITUDES AND MEAN LATITUDES OF STATIONS LOCATED IN THE VICINITY OF A COMMON MERIDIAN IN THE PERIOD 1962-1975

Barbara Kolaczek, Roman Galas, Marcin Barlik, Magdalena Dukwicz

I. Introduction

Changes of geographical latitude are caused mainly by free or forced nutation of the axis of Earth's rotation. In addition, changes of geographical latitude are affected by a number of other factors such as errors in astronomical constants and in declination of stars, instrumental errors, inaccurate theory of nutation and refraction, and also local movements of Earth's crust and changes in the plumb direction.

Local movements of Earth's crust and changes in the plumb (vertical) direction result mainly in secular and irregular changes of the mean geographical latitude, that is the latitude freed from periodical variations. The mean latitude of a station is also influenced by irregular and secular instrumental changes and refractional anomalies. On one hand, local changes of latitude are superimposed on changes caused by movements of poles, complicating the picture. On the other hand, local changes of latitude contain information on the local movements of the Earth's crust - both those connected with tectonic plate displacements and with local mass movements caused, for instance, by

earthquakes. Investigation of the local changes of latitude may, therefore, facilitate studies of the movements of poles and may contribute to studies of tectonic plate displacements. The uniform observations of changes in latitude over a period of years represent a unique bank of data for geodynamic studies.

The secular local changes of latitude for some stations have been determined (/1/, /5/, /6/, /14/, /17/, /21/) and they are usually interpreted as movements of tectonic plates. Irregular sudden changes of the mean latitude of the order of 0".1 (several months) have also been noted /4/, /13/. However, the reasons for their appearance remain unknown. Investigation of correlation between the local changes of latitude and the better-known now extents of displacement of tectonic plates, the occurrence of earthquakes near stations located in active seismic regions, and finally changes in plumb line, would enable to explain main reasons for local changes of latitude.

To explain the character of the local changes of latitude we analyzed in this work changes of mean latitude and differences between mean latitudes for stations located near the meridian of station Jozefoslaw. The placement of these stations is particularly suitable for this investigation. Moreover, this work covers also experimental results of gravimetric measurements, carried out at the meridional base Jozefoslaw to determine meridional component changes in the plumb line and their effect on changes of latitude.

II. Changes of mean latitude and differences of mean latitudes for stations located near a common meridian

Differences of geographical latitude and mean latitude for stations located in the vicinity of a common meridian are particularly suitable for studies of the effect of local factors since the effect of the movements of pole is here eliminated. Changes in differences of the mean latitude of Jozefoslaw and Belgrade have been noted for the first time by Teleki /20/. In the present work we analyzed changes of mean latitudes and their differences for four stations located near a common meridian, namely, Turku, Jozefoslaw, Belgrade and Pečny. Turku is situated in the area of large vertical movements of the Northern shores of Baltic, while Belgrade is located in a seismically active region, near the boundaries of two tectonic plates. In these areas, local movements of Earth's crust, and the associated changes in latitudes of stations, can be expected. For comparison, changes of mean latitudes of several European stations have also been calculated. Table 1 gives coordinates of the considered stations.

On the basis of data published by IPMS in "Annual Report" for the period 1962-1973 /9/ and in "Monthly Notes" for the period 1973-1975 /10/ we calculated mean latitudes of these stations, using an Orlov-OR2 filter. By application of the method of harmonic analysis we calculated also the so-called filtered latitude of these stations /8/. The filtered latitude

was obtained as a result of elimination from the observational data of all the latitudes in periodic values whose amplitude exceeded the mean error of determination, that is the value of 0".004-0".008. The determined periodic values of the variations of latitude for the considered stations in the period 1962-1975 are presented in Table 2. Graphs of the mean latitudes counted with the Orlov filter and of the filtered latitudes are shown in Figure 1. On Figure 1 we marked also by arrows the moments of occurrence of larger (M > 5.5) earthquakes in the region of Belgrade (at a distance shorter than 2000 km), and the instrumental changes reported by observatories in Turku and Belgrade.

We calculated also differences of latitudes as well as differences of mean latitudes calculated with Orlov formula for the considered stations. The graphs of these latter differences are shwon in Fig. 2. Changes of differences in the mean latitudes represent now only the relative changes of the mean latitudes of stations caused by the local factors.

Variations of mean latitudes, counted with Orlov filter, and their differences for the remaining European stations are shown in Figures 3 and 4.

The analysis of variations in mean latitudes and their differences enables to draw the following conclusions.

1. The largest variations of the mean latitude occur in Belgrade, that is the station situated in a seismically active zone. On Figure 1b one can notice a correlation between the sudden decrease of the mean latitude of Belgrade and the

earthquake in Skopie No. 0 (Table 3), as well as other smaller earthquakes No. 2, 4, 6. The earthquake No. 12, whose epicenter was located closer to Belgrade than all the remaining earthquakes, coincides also with a sudden change of the mean latitude, and also with the then introduced thermal protection of "libel". The seismic activity in the region of Belgrade meridian was more pronounces in the years 1964-1966, 1968-1970 and 1972 and it correlated with larger changes of the mean latitude of Belgrade, as well as differences of mean latitude of Belgrade and Jozefoslaw.

2. Variations of the mean latitude of stations as well as their differences are smaller in the case of continental stations (Jozefoslaw, Pečny, Paris), and larger for stations located nearer to seashores (Turku, Hamburg, Uccle).

3. On the basis of available data it is difficult to explain the reasons for such sudden changes in latitude as for Turku in 1972, for Uccle in 1965 and 1972, and for Hamburg in 1972. It is known that Turku lies in the region of large vertical movements of seashore of the Baltic Sea, hence in an unstable area where local displacements of mass in the region of station can take place.

Because of the short period of time and special choice of stations, the analyzed variations of the mean latitude did not allow to draw conclusions with respect to the displacements of tectonic plates.

4. The curves of variations of the filtered latitude of station (Figure 1) enable to register in more detail the irregular changes than does the mean latitude counted with very approximating (smoothing) Orlov filter, as can be seen, for instance, in the case of Turku. Moreover, spectrally filtered curve of changes in latitude provides an information about secular and irregular changes of latitude throughout the whole period considered, without omitting the one-year-and-a-half or three-year end periods, as happens in the cases of the Orlov or BIH filters. This fact is of prime importance in studies of variations of the mean latitude.

5. In addition to main parameters of periodic expressions for changes of latitude, that is the Chandler expression and the annual and semiannual expressions, the parameters of many other periodic expressions were determined as a result of harmonic analysis (Table 2). Some of them are known in the literature and some attempts of physical interpretation have been made for them, as noted in Remarks of Table 2. However, in the interpretation of these expressions one has to remember that some artificial periodic expressions can arise as a consequence of methods of treatment of experimental data and of the application of the method of harmonic analysis to a process which is not exactly fully suitable for it. In values of the mean latitude counted with the aid of Orlov formula for stations Jozefoslaw, Turku, Belgrade and Pečny there occurred quite

distinct long-period expressions having the periods 2.6-2.8 years and the amplitudes 0".01-0".02 (/18/ , /2/).

Further analysis of variations of the mean latitude of satations considered here and of other stations located in different geophysical regions may help to explain the character of local changes in the latitudes of stations, and also may eventually give selection of latitudinal stations whose observational data would not contain large local disturbances.

III. Determination of changes in the plumb line at the meridian of Jozefoslaw through gravimetric measurements

III.1. Introduction

Lunisolar influences and dislocation of mass inside the Earth, including the displacement of tectonic plates, exert effect upon the orientation of equipotential surface at the point of observation, that is on the orientation of the actual plumb line. Changes in the direction of plumb line $d\xi$ enter directly into determination of the astronomical geographical latitude, since $d\varphi = d\xi$. To present mathematically the form of this dependence we shall make use of the well known equation describing the change of the plumb line on account of lunar and solar effects

$$d\xi = -\frac{3}{2} Ak \frac{m}{g} \cdot \frac{r}{R^3} \sin 2z, \qquad (1)$$

where k - gravitational constant, m - mass of Sun (Moon), r - radius of Earth, R - distance to Sun (Moon), z - zenith distance of Sun (Moon), $\Lambda = 1 + \chi - l$ where χ and l denote Love's numbers characterizing the compressibility of Earth. The value of Λ is 1.13, and in our considerations we shall assume it to be a constant with time.

Instead of the potential of attraction of Sun (Moon), one can use in the above equation the potential of attraction of an additional mass inside the Earth. It could be located under the surface periodically as, for instance, ground water, or it could appear in a sudden manner as it happens in the case of an earthquake. This movement should reflect itself also in changes of equipotential surface and direction of the plumb line, provided these displacements involve sufficiently large masses. The direction of the plumb line can be calculated from the equations of Vening Meinesz. The meridional component $d\xi$ of the deviation of plumb line with gradient of gravimetric anomaly Ag can be represented by equation

$$d\xi = 0.''105 \cdot d \cdot \frac{Ag_S - Ag_N}{2d} = 0.''0525(Ag_S - Ag_N), \qquad (2)$$

where d denotes the distance of points N and S of the base, and Ag denotes Faye's gravimetric anomaly determined at those points. The coefficient 0.105 arises from theory of the method of Vening Meinesz.

After time interval between consecutive observations δg_S and δg_N, changes in gravimetric anomaly will cause changes in the direction of the plumb line by the amount

$$\Delta\xi = 0\overset{''}{.}0525(\delta g_S - \delta g_N). \tag{3}$$

The above considerations are valid only for the model of rigid Earth. For the real Earth the last equation should be modified by introduction of the Love's numbers. The measured differences of acceleration are $G = 1 + h - \frac{3}{2}k$ = 1.20 times larger than those for the model of rigid Earth. In turn, the observed values of geographical latitude are $\Lambda = 1 + k - l$ larger than those obtained from the equation (3). Finally, we get the working formula for the described method:

$$\Delta\varphi = \Delta\xi = 0\overset{''}{.}0525\frac{\Lambda}{G}\cdot\delta\Delta g = 0\overset{''}{.}0494\delta\Delta g. \tag{4}$$

A simple analysis of this equation will show that, in order to detect a change of the mean latitude of the observatory of the order of 0".001, the error of determination of changes in acceleration should not exceed ± 20 µ gal. The required accuracy of the determination of $\delta\Delta g$ dictates and limits the method of gravimetric work and the type of used instruments. This accuracy can be achieved by means of modern, astatisized quartz instruments.

III.2. Results of determination of changes in the direction of plumb line at Jozefoslaw in the period of one year

On the basis of given above considerations we performed experimental determination of changes of the mean geographical latitude of Jozefoslaw caused by movements of the direction of plumb line (vertical). For this purpose, we established a meridional gravimetric base containing seven measurement points, namely:

N14 - a point 14 km North of Jozefoslaw station; N6 - a point 6 km North of station; N3 - a point distant 3 km North of the station; and similarly points S14 , S6 and S3 located correspondingly at the distance of 14, 6 and 3 kilometers South of the Jozefoslaw station.

All these points were chosen following the strictest requirements which apply to establishing a network of basic gravimetric points. The distances between points of the base were such that by means of repeated gravimetric measurements one could detect dislocations of mass near the Jozefoslaw station - point O, movements of mass of the Earth crust, and movements of even deeper layers of Earth to Mohorovičić boundary (points N14 and S14). Feitelson et al. /7/ suggested the utilization of a surface gravimetric picture of area up to 200 km from the station for this purpose. Such a large outline of the picture does not allow to carry out fast periodic repeats of measurements

to determine changes in the direction of plumb line. Therefore, for this work we adopted the concept of measurements on meridional gravimetric base, so much more that we are primarily interested in changes of the meridional component of the direction of plumb line. Measurements of differences of the acceleration at the base were performed by means of gravimeters Worden No. 867, or Sharpe Nos. 129, 185, 202 and 203.

The uniform scale of determined values Δg was ensured through standardizing gravimetry by the method of inclination on examinator. The measurements carried out so far were in four series: 10-11 June 1976, 6-9 November 1976, 9 March 1977, and 5-7 May 1977. In each series the observations were made in three rounds, and the spread of measurements over several days was intended to provide a better averaging of the results of observations. Appropriate instrumental adjustments and lunisolar corrections were introduced into the results. Table 4 presents differences Δg, and their mean errors for particular sections of the base and for particular series of measurements. The Table lists also changes in the direction of plumb line (vertical) calculated according to the formula (4).

As a result we obtained the following changes:

In the period from June 1976 to November 1976

$$\Delta\varphi = -0.''0024 \pm 0.''0015;$$

In the period from November 1976 to March 1977

$$\Delta\varphi = +0.''0019 \pm 0.''0018;$$

In the period from March to May 1977

$$\Delta\varphi = -0''.0030 \pm 0''.0012.$$

The obtained results indicate the possibility of registration by this method of changes in geographical latitude of the order of $0''.01$ caused by movements of the plumb line. These first experimental results do not justify yet physical interpretation of the registered changes in mean latitude. Small changes of the mean latitude require the introduction of a large number of measurements in short intervals of time. The use of a larger number of instruments would allow to eliminate systematic errors of the instruments. Performing of such gravimetric measurements at latitudinal stations situated in seismically active regions, as for instance Belgrade, would allow a deeper geophysical interpretation of changes in the mean geographical latitude.

Table 1. Coordinates of the considered latitudinal stations.

(1) Stacja	λ	φ	(1) Stacja	λ	φ
Turku	-1^h29^m	60°27′	Uccle	-0^h17^m	50°48′
Józefosław	-1^h24^m	52°06′	Paris	-0^h09^m	48°50′
Belgrad	-1^h22^m	44°48′	Neuchatel	-0^h28^m	47°04′
Pečny	-0^h58^m	49°54′	Hamburg	-0^h40^m	53°36′

Key: (1) Station.

Table 2. Periodicities of changes in the mean latitude of stations located at a meridian common to station Jozefoslaw, determined in the process of filtration.

Józefosław p	Józefosław A	Turku p	Turku A	Pečny p	Pečny A	Belgrad p	Belgrad A	Uwagi (1)
1″.193	0″.131	1″.178	0″.112	1″.180	0″.109	1″.188	0″.143	w. Chanlera (2)
1.005	0.162	1.008	0.101	0.996	0.125	1.030	0.124	w. roczny (3)
0.609	0.029	0.502	0.031	0.595	0.010	0.530	0.034	w. półroczny (4)
—	—	—	—	0.330	0.047	0.321	0.034	wpływ anomalii refrakcji [37] (5)
—	—	—	—	.350	0.017	.338	.014	
—	—	—	—	.394	.023	.375	.018	
0.427	0.013	0.408	0.011	.424	.015	.415	0.25	
—	—	.443	.010	.439	.021	.424	0.14	
.473	.013	—	—	.463	.014	.436	.028	
—	—	—	—	.487	.027	.468	.019	wpływ okołodobowej nutacji swobodnej [11], [12], [15] (6)
—	—	.513	.011	—	—	.504	.021	
.568	.011	.585	.008	.551	.021	.536	.015	
—	—	—	—	—	—	.577	.014	
—	—	—	—	.632	.013	.624	.014	
.692	.015	.680	.013	.658	.019	.658	.012	
.767	.016	.723	.010	.709	.011	.784	.016	
.909	.010	.882	0.16	.883	.022	.881	0.17	
.950	.031	—	—	—	—	.962	.055	wpływ błędu stałej nutacji [18] (7)
1.050	.016	—	-	1.129	.017	1.075	.017	
1.312	.027	1.324	.021	1.334	.029	1.268	.034	wpływ oscylacji oceanu [16] (8)
		1.516	.016	—	—	1.448	.013	
—	—	—	—	1.650	.015	1.637	.011	[18]
1.939	.014	1.815	.012	2.020	.017	2.090	.011	wpływy meteorologiczne [2] (9)
2.444	.009	2.374	.034	2.507	.015	—	-	

Key: (1) Remarks; (2) Chanler period; (3) Annual period; (4) Semiannual period; (5) Effect of refraction anomaly [37]; (6) Effect of diurnal free nutation [11], [12], [15]; (7) Effect of the error of constant nutation [18]; (8) Effect of oscillation of ocean [16]; (9) Meteorological effects [2].

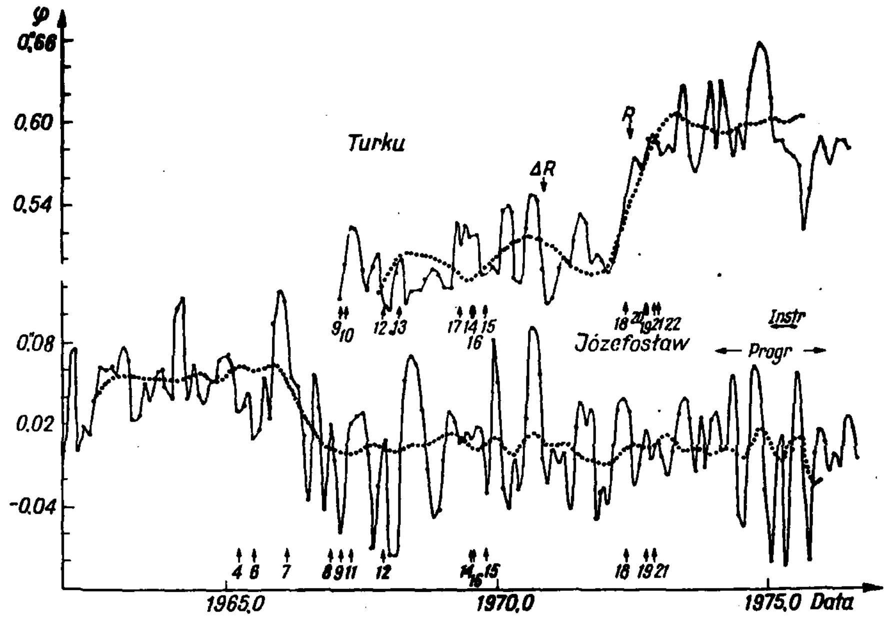


Figure 1a. Curves of changes in the mean and filtered latitude of stations Turku and Jozefoslaw.

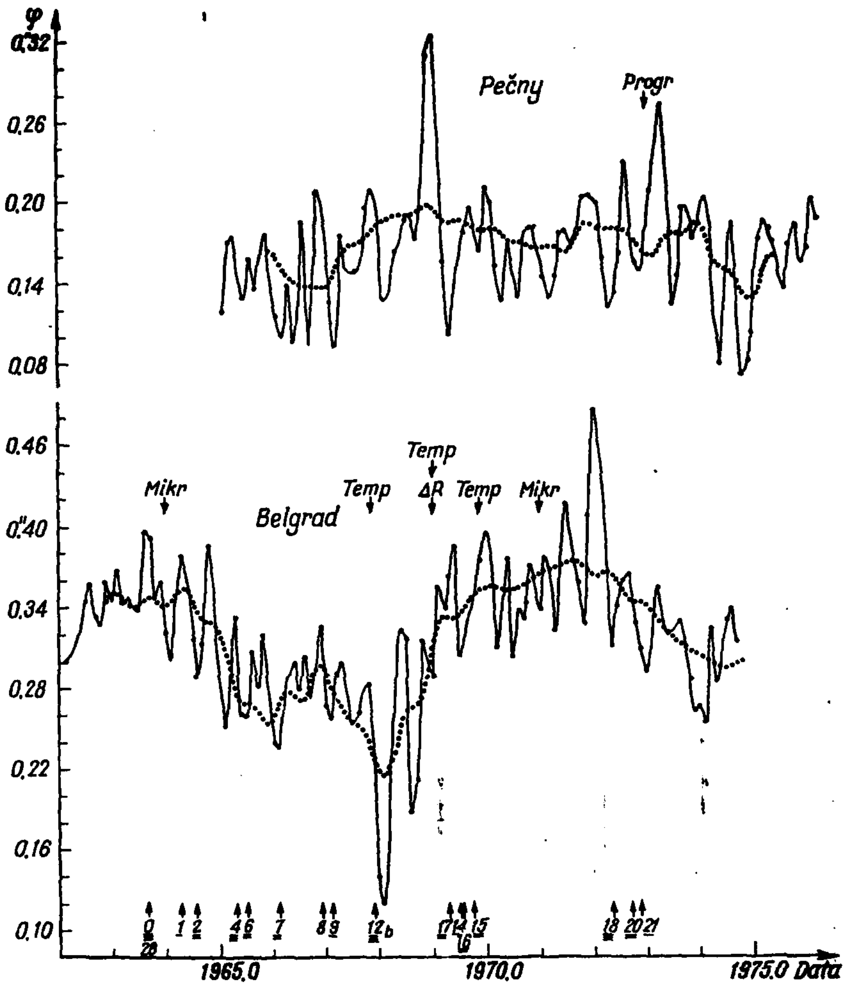


Figure 1b. Curves of changes in the mean and filtered latitude of stations Pecny and Belgrade.

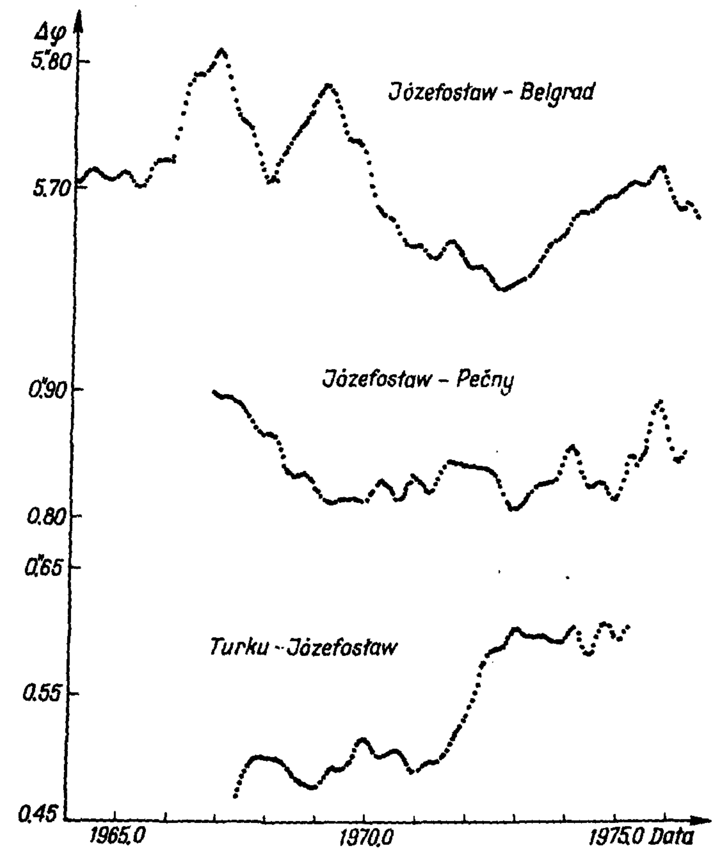


Figure 2. Curves of changes in the mean latitude of stations located in the vicinity of a common meridian.

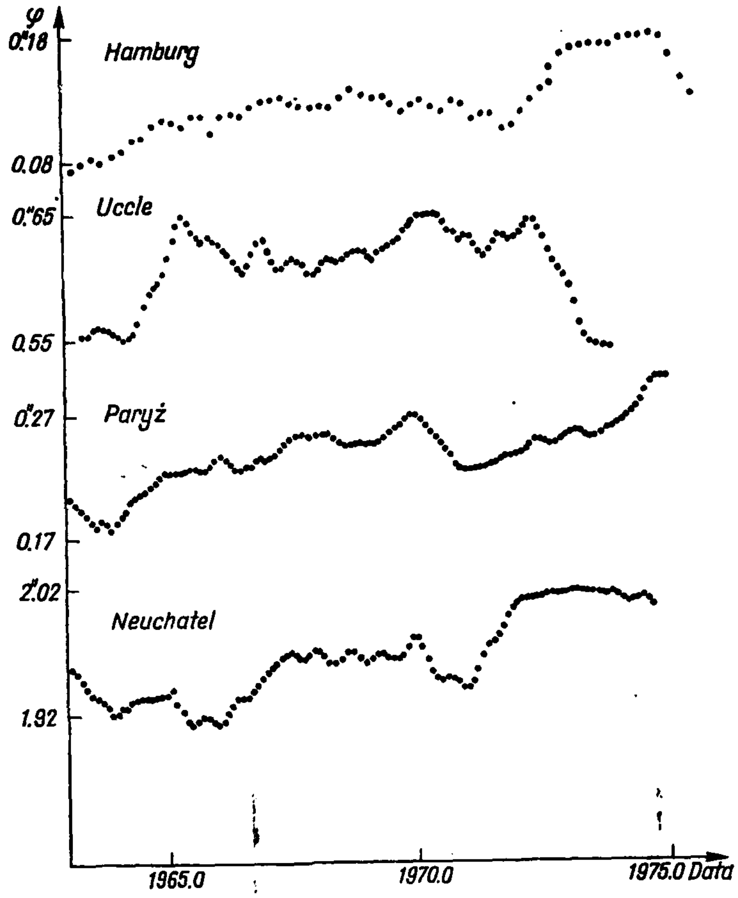


Figure 3. Curves of changes in the mean latitude of selected European stations.

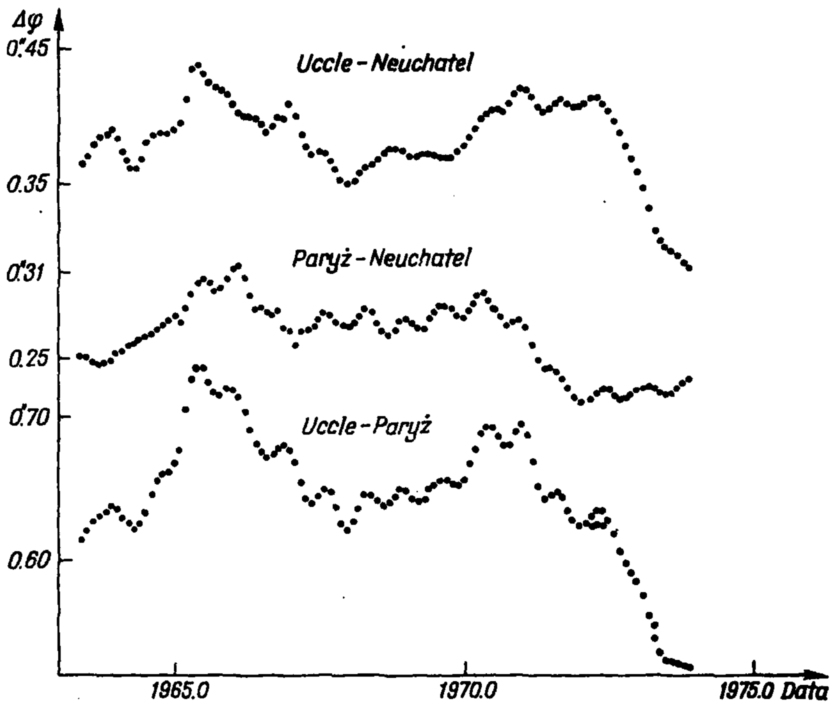


Figure 4. Curves of changes of differences in the mean latitude for selected European stations.

Table 3. List of larger earthquakes (M>5.5) in vicinity of Belgrade.

Nr	Data	*N*	*E*	*h* (km)	*M*	Rejon (1)
0						Skopie, Jug. (2)
1	1964 04 13	45°3	18°0	5	5.5	Jugosławia (3)
2	07 17	38.0	23.6	155	5.7	Grecja (4)
3	1965 03 09	39.3	23.8	18	5.7	Morze Egejskie (5)
4	03 31	38.4	22.3	45	6.3	Grecja (4)
5	04 09	35.1	24.3	39	5.9	Kreta (6)
6	07 06	38.4	22.4	18	5.8	Grecja (4)
7	1966 02 05	39.1	21.7	16	5.6	Grecja (4)
8	10 29	38.9	21.1	1	5.8	Grecja (4)
9	1967 02 09	39.9	20.3	1	5.6	Albania (7)
10	03 04	39.2	24.6	60	6.0	Morze Egejskie (5)
11	05 01	39.6	21.3	34	5.5	Grecja (4)
12	11 30	41.4	20.4	21	5.9	Albania (7)
13	1968 02 10	39.4	24.9	7	6.0	Morze Egejskie (5)
14	1969 07 08	37.5	20.3	0	5.5	Morze Jońskie (8)
16	06 12	34.4	25.0	22	5.8	Kreta (6)
17	1970 04 08	38.3	22.6	23	5.8	Grecja (4)
18	1972 05 04	35.2	23.6	14	5.9	Kreta (6)
19	09 17	38.4	20.3	33	5.6	Grecja (4)
20	09 13	38.0	22.4	75	5.8	Grecja (4)
21	11.04	38.9	20.5	13	5.6	Grecja (4)
22	11 29	35.2	23.8	37	5.6	Kreta (6)

Key: (1) Region; (2) Skopie, Yugoslavia; (3) Yugoslavia; (4) Greece; (5) Aegeian Sea; (6) Crete; (7) Albany; (8) Ionian Sea.

Table 4a. Values of Δq for meridional base of Jozefoslaw station in milligals.

Nr serii	N14–S14		N6–S6		N3–S3	
	Δg	$m_{\Delta g}$	Δg	$m_{\Delta g}$	Δg	$m_{\Delta g}$
I	−19.442	±0.018	−8.281	±0.012	−4.963	±0.012
II	−19.530	±0.019	−8.337	±0.010	−4.961	±0.012
III	−19.441	±0.029	−8.342	±0.016	−4.929	±0.006
IV	−19.426	±0.019	−8.497	±0.016	−4.970	±0.010

Table 4b. Values of q and Δq for meridional base Jozefoslaw.

Nr serii	N14–41S		N6–S6		N3–S3	
	$\delta\Delta g$ $\Delta\varphi$	$m_{\delta\Delta g}$ $m_{\Delta\varphi}$	$\delta\Delta g$ $\Delta\varphi$	$m_{\delta\Delta g}$ $m_{\Delta\varphi}$	$\delta\Delta g$ $\Delta\varphi$	$m_{\delta\Delta g}$ $m_{\Delta\varphi}$
II–I	−0.008 −0."0044	±0.0265 ±0."0013	−0.056 −0."0028	+0.015 ±0."0007	+0.002 +0."0001	±0.017 ±0."0008
III–II	+0.089 +0."0044	±0.034 ±0."0017	−0.005 −0."0002	±0.019 ±0."0009	+0.032 +0."0015	±0.013 ±0."0006
IV–III	+0.015 +0."0007	+0.034 ±0."0017	−0.029 −0."0014	±0.023 ±0."0011	−0.041 −0."0020	±0.012 ±0."0006

REFERENCES

[1] Arrur M. G., Mueller I. I. *Latitude observations and the detection of continental drift* J. Geoph. Res. Vol. 76 No. 6, 1971.

[2] Dejaiffe R. J., Melchior P. J., *On periodicities found in investigating the closing errors in all the ILS stations*, Astr. and Astroph., No. 14, 1971.

[3] Djurović D., *Sur un terme harmonique de 122 jours dans la rotation de la Terre et dans le mouvement du pole*, Ciel et Terre, Vol. 90, No. 1, 45, 1974.

[4] Enslin H., *The variation of the mean latitude of the Hamburg PZT*; Proc. IAU Colloq. No. 1 — *The problem of the variation of the geographical coordinates in the southern hemisphere*, La Plata 1968.

[5] Fedorov E. P., Korsuń A. A., Mironov N. T., *Non periodic latitude variations and the secular motion of the Earth's pole*, Proc. IAU Symp. No. 48 — *Rotation of th. Earth*, Marioka 1972.

[6] Feissel M., *An astronomical measurements of the present day drift*, Geoph. J. Roy. Astr. Soc. Vol. 38, 1974.

[7] Faitelson A. S., Mironov A. S., Yurkina M. I., *Slow variations of the Earth's gravity field and recent crustal movements*, Report given at the XVI IUGG General Assembly, Grenoble 1975.

[8] Galas R., *Application of the spectral analysis to computation of filtered latitude*, Report given at the 3rd Int. Symp. — Geodesy and Physics of the Earth, Weimar 1976.

[9] IPMS Annual Report, 1962—1973.

[10] IPMS Monthly Notes, 1972—1975.

[11] Jackiw J., Wako Y., Kencko Y., *Study of the nearly diurnal free nutation based on latitude observations of the ILS stations*, Publ. of the Int. Lat. Obs. of Mizusawa, Vol. X No. 1, 1975.

[12] Jeffreys H., Vicente R. O., *The theory of nutation and variation of latitude*, Monthly Not. Roy. Soc. Vol. 117.

[13] McCarthy D. D., *Secular and nonpolar variation of Washington latitude*, Proc. IAU Symp. No. 48 — *Rotation of the Earth*, Marioka 1972.

[14] Mironov N. T., *Variations of the angles between the plumb lines of the astronomical instruments*, Proc. of the IAU Colloq. No. 26 — *On the reference coordinate systems for Earth dynamics*, Toruń 1974.

[15] Molodensky M. S., *The theory of nutation and diurnal Earth's tides*, Comm. Obs. Roy . Belg., No. 188, 1961.

[16] Naito I., Ishi H., *Secular variation on spectral structures of z-term in latitude variation*, Publ. Astr. Soc. Japan, No. 26, 1974.

[17] Proverbio E., Quesada V., *Velocity and direction of plate displacements by latitude observations*, Ann. Geofisica, Vol. XXVI, No. 2—3, 1973.

[18] Provrebio E., Quesada V., *Periodic and quasi-periodic fluctuations in the motion of the Earth's pole;* Publ. Staz. Inst. Lat. Carlofortecagliari, Nuova Ser. No. 45.

[19] Rogowski J. B., *Nonpolar latitude variation at Józefosław*, Prace Naukowe Politechniki Warszawskiej, Geodezja, No. 19, 1977.

[20] Teleki G., *Comparison of latitude variations obtained from observations in Belgrade and Józefosław*, Bull. de l'Óbs. Astr. de Beograd, Vol. XXVII, No. 2, 1969.

[21] Yumi S., *Nonpolar variation of latitude*, Proc. IAU Colloq. No. 1 — *The problem of the variation of the geographical coordinates in the sourthern hemisphere*, La Plata 1968.

Summary

Differences of latitudes and of mean latitudes of stations located along a common meridian were studied in order to find influences of local geophysical phenomena on their variations. Some correlations of variations of the mean latitude of Belgrade with an occurance of earthquakes in its vicinity can be noticed as well as instabilities of mean latitude of stations located in the vicinity of sea coasts.

Results of experimental gravimetric measurements of variations of a meridian component of a vertical on the meridian base of the Józefosław station are presented.

GEOMETRIC METHOD OF DETERMINATION OF THE SHAPE OF EARTH IN MOUNTAINOUS TERRAINS

Aniela Makowska, Zbigniew Żorski

1. Introduction

The analyses carried out in works /6/, /7/ lead to the conclusion that there is a possibility of simultaneous determination, from equalization of trigonometric height network, of excessive heights, deviation of plumb line (component deviations of vertical) and coefficients of refraction at each point of the network.

This method of utilization of the results of trigonometric levelling in mountainous terrains provides information on both the building of atmosphere (coefficients of refraction) and the weight (mass) field of Earth (components of the deviations of plumb lines) and, at the same time, enables to determine ellipsoidal heights (heights counted along the normal to ellipsoid of the physical surface of Earth).

In view of difficulties of determination of the shape of Earth in mountainous terrains by astronomical-geodetic and gravimetric methods,/2/, trigonometric levelling may be considered as an auxiliary, geometric method to determine the shape of Earth in those terrains. However, the accuracy of determination of heights and of plumb line deviations by means of geometric method is strictly dependent on accurate knowledge of the coefficients of refraction.

The treatment of the refraction phenomenon in the form of a mathematical model with constant coefficients of refraction at stands (stations), as suggested in works /4/ and /5/, is a large step forward in this field. However, it will be the subject of this work to find whether the such accepted mathematical model for refraction corresponds to the real conditions governing in mountainous terrains. The analyses will be carried out on the basis of measurements made in Polish Tatra Mountains.

2. Method of determination

Measurements of vertical angles and lengths of sides were carried out in July and August 1974. The angle measurements were done under direction of the authoress, and linear measurements by Drs. R. Kleczko and T. Jasinski, on seven points of the Tatra network (Figure 1). During the measurements the weather was changeable but mostly sunny. For observation of angles we used theodolits Wild T3; they were checked before the use - and errors in the division of vertical circle /8/ and of micrometer (of runs and systematic errors) were determined. For precise measurements of vertical angles, however, special attention should be paid to instrumental and operator errors, since in this type of instruments there is no possibility of displacing the vertical circle and micrometer (we measure at the same point of wheel and micrometer, and we measure only one direction).

In order to determine personal errors, measurements were made by several observers taking part in the project; they were made simultaneously with several instruments, measuring vertical angles of several targets located at different heights. Heliotropes and reflectors served as the targets. The vertical angles in the network were measured in four series, each series consisting of four aimings at two positions of the wheel (circle). Forty vertical angles were measured. The lengths of sides in the network were measured by means of an electrooptic laser rangefinder of the Swedish firm AGA Model 8. Standard frequencies of the rangefinder were checked before and after measurements of the network. The value of the addition constant and the linearity of the scale of phasometer were checked on the standard base P.W.

The sides were measured in both directions.

3. Discussion of results

The following correction equation /7/ was applied to each observed zenithal distance:

$$V_{ij}^{cc} = \frac{\sin Z_{ij}}{S_{ij}} \varrho^{cc} dH_i - \frac{\sin Z_{ji}}{S_{ij}} \varrho^{cc} dH_j - \xi_i \cos\alpha_{ij} - \eta_i \sin\alpha_{ij} - \frac{1}{2} \frac{S_{ij}}{R_{ij}} \varrho^{cc} \Delta K_i + l, \tag{1}$$

where

Z_{ij} - zenithal distance,

S_{ij} - spatial distance between points P_i, P_j

R_{ij} - radius of curvature of the normal cross-section of ellipsoid in azimuth α_{ij}

ξ_i ; η_i - components of deviations of plumb line (meridional and in the first vertical),

ΔK_i - correction to approximate coefficient of refraction at i-th position

l - free expression

in which

$$l = \frac{\Delta H_{ij} - \Delta H_{ij}^0}{S_{ij} \sin Z_{ij}} \cdot \varrho^{cc},$$

$$\Delta H_{ij} = S_{ij} \cos\left(Z_{ij} + \delta_i - \frac{\gamma}{2}\right) \sec\frac{\gamma}{2},$$

whereas:

ΔH_{ij}^0 - approximate ellipsoidal difference of height

$\delta_i = \frac{1}{2} \frac{S_{ij}}{R_{ij}} K_0$ - angle of vertical refraction

γ_{ij} - medium angle between normals to ellipsoid neglecting the whirl, calculated for instance from formula /7/ Figure 1:

$$\gamma^{cc} = \frac{S_{ij}}{R_{ij} + H_i} \sin(Z_{ji} + \delta_i) \cdot \varrho^{cc}.$$

The levelling of the Tatra trigonometric network was done by an indirect method in several variants.

In Variant I we assume knowledge of the height of Point 1 and of the deviations of vertical (plumb line) at all points (from astronomical-gravimetric measurements), and it remains to determine hight differences and coefficients of refraction constant at the station. The levelling results are presented

in Table 1. Lines 1-6 contain differences between ellipsoidal heights calculated on the basis of results of precise levelling (orthometric heights H^{at}) and astronomical-gravimetric levelling (interval between geoid and ellipsoid placed tangentially to geoid at the point 1-N), and heights obtained from the trigonomical levelling of network. Lines 7-18 contain components of the deviations of plumb line (it was assumed that at Point 1 $\xi_1 = 0$ and $\eta_1 = 0$). Lines 19-28 contain coefficients of refraction for each position.

For Variant I, discrepancies between the determined heights are quite high, up to 13 cm. Also, differences between coefficients of refraction obtained from the levelling of network and from geodetic measurements are considerable, reaching, for example, $\Delta K = 0.035$ for the Point 1. The conclusion that follows is that the adopted mathematical model for refraction, which assumes the constancy of refraction coefficients at each position, corresponds only approximately to the real conditions governing at the Tatra grounds.

We introduced into equation, therefore, additional unknowns in view of differences of ground cover and shape for each line of sight. We changed refraction coefficients for points 1 and 4 since the lines of sight for these points were running partly over forests and partly over sunny Southern slopes. This is now Variant II. The adoption of this model reduced considerably discrepancies both for heights and for coefficients of refraction

(Table 1). The same model was further modified by assuming only two constant points, one with known height and deviation of vertical and the other with deviation of vertical (Variant II^{a}, Table 1).

On the other hand, Variant III refers to a model with constant coefficient of refraction for the whole network. Assuming knowledge of height at Point 1 and knowledge of the deviation of verticals at all points, we determine from the leveling only differences in height and the constant coefficient of refraction for the whole network (Table 1).

Summing up the results of this analysis we have to conclude that the acceptance of a mathematical model for refraction, with constant refraction coefficients at a station, is not always appropriate, particularly when the lines of sight run over slopes with different exposures to sun and over terrain with different vegetation cover around the station (points 1 and 4). It is recommended, therefore, to use in levelling a model with group refraction coefficient at the station, particularly for points lying low (less than about 1100 m above sea level). This procedure provided us with an accuracy of determination of the components of deviation of vertical to $\pm 6^{cc}$, and of the height to ± 4 cm. The accuracy of determination of the deviations of vertical by the astronomical-gravimetric method is estimated at $\pm 3^{cc}$ /2/. This comparison entitles us to draw

conclusion that the trigonometric levelling can be used as an auxiliary, geometric method of determination of the shape of Earth in mountainous terrains.

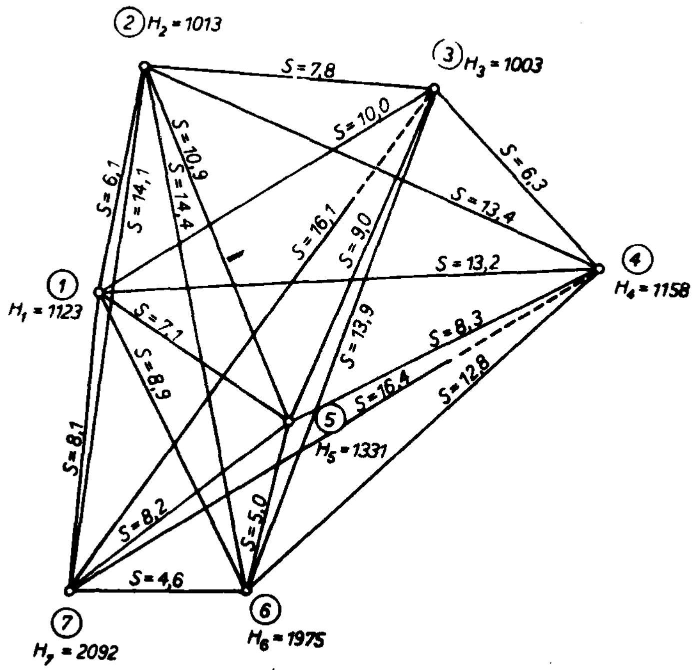


Figure 1.

Table 1. Results of trigonometric levelling of elevation network.

Nr wariantu	I		II		II^a		III	
	Δ	m_i	Δ	m_i	Δ	m_i	Δ	m_i
dH_2 [cm]	+8,7	±3,3	+1,7	±1,9	+2,2	±3.9	+4,0	±3,9
dH_3 [cm]	+5.6	±4,2	−2,7	±2,4	+0,9	±4,7	+4,7	±4,3
dH_4 [cm]	−3,5	±4,5	−3,9	±2,3	−4,6	±4,6	0,0	±4,2
dH_5 [cm]	−5,6	±3,5	−2,6	±1,9	−0.4	±2,7	−7,5	±3,7
dH_6 [cm]	−9,5	±3,5	−2,9	±2,0	−2,0	±3,6	−11,6	±3,9
dH_7 [cm]	−13,3	±3,6	−2,7	±2,1	−4,1	±3,2	−13,9	±4,1
$\xi_2^{[cc]}$	—	—	—	—	−2,1	±5,3	—	—
$\eta_2^{[cc]}$	—	—	—	—	−0,2	±3,9	—	—
$\xi_3^{[cc]}$	—	—	—	—	+2,1	±5,8	—	—
$\eta_3^{[cc]}$	—	—	—	—	−1,6	±5,6	—	—
$\xi_4^{[cc]}$	—	—	—	—	+7,5	±5,3	—	—
$\eta_4^{[cc]}$	—	—	—	—	−2,7	±5,7	—	—
$\xi_5^{[cc]}$	—	—	—	—	+24,1	±3,4	—	—
$\eta_5^{[cc]}$	—	—	—	—	+10,5	±3,4	—	—
$\xi_6^{[cc]}$	—	—	—	—	—	—	—	—
$\eta_6^{[cc]}$	—	—	—	—	—	—	—	—
$\xi_7^{[cc]}$	—	—	—	—	+10,5	±5,5	—	—
$\eta_7^{[cc]}$	—	—	—	—	+1,1	±4,2	—	—
ΔK_1			0.159	±0.006	0,155	±0,010		
$\Delta K_1'$	0,125	±0,006	0,126	±0,004	0,120	±0,006		
$\Delta K_1''$			0,096	±0,006	0,093	±0,008		
ΔK_2	0,125	±0,005	0,118	±0,003	0,112	±0,010		
ΔK_3	0,117	±0,006	0,107	±0,004	0,107	±0,011		
ΔK_4	0,091	±0,005	0,097	±0,003	0,107	±0,011	0,117	±0,002
$\Delta K_4'$			0,114	±0,004	0,127	±0,013		
ΔK_5	0,127	±0,006	0,133	±0,004	0,137	±0,006		
ΔK_6	0,126	±0,005	0,134	±0,003	0,133	±0,005		
ΔK_7	0,120	±0,004	0,126	±0,002	0,120	±0,009		
m_0	$\pm 5^{cc},2$		$\pm 2^{cc},7$		$\pm 2^{cc},6$		$\pm 7^{cc},9$	

REFERENCES

[1] Alberda J. E., *Vertical angles, deviations of the verstical and adjustment*, Rijkscommissie voor geodesie Delft 1961.

[2] Barlik M., *Wyznaczanie rzeczywistych odchyleń pionów w górach*, Geodezja i Kartografia, t. XXV, z. 3, 1976.

[3] Gleinsvik P., *Studien über die Ermittlung der Geoidform und die Bestimmung von Meereshöhen aus Höhenwinkeln*, Vlg. Leemann, Zurich 1960.

[4] Hradilek L., *Bestimmung der relativen Lotahveichungen und der Refraktionskoefficienten beim Ausglich trigonometrisch gemessener Höhennetre*, Studia geoph. et geod. 1958, 1959, 1960.

[5] Hradilek L., *Theoretische Bergündung der Methode für Refraktions und Lotahweichungsbestimmung auf jedem Punkte eines trigonometrischen Höhennetres*, Studia geoph. et geod. 1963.

[6] Makowska A., *Trygonometryczna sieć w terenach górskich*. Geodezja i Kartografia, t. XXI, z. 3, 1972.

[7] Makowska A., Zorski Z., *Analiza wyrównania trygonometrycznej sieci wysokościowej z uwzględnieniem odchyleń pionów i refracji*, Geodezja i Kartografia, t. XXV, z. 1, 19756.

[8] Stańczyk Z., *Mechaniczno-elektroniczne urządzenie do badania błędów podziału kół poziomych i pionowych*, Prace naukowe PW, Geodezja, 1969, nr 3.

Summary

In the article the refraction formula for trigonometric levelling in mountains is analysed.

It is shown in the work that constant coefficient of refraction is not always appriopriate in surveys, particularly when lines of sight run over the sun heated slopes, or over the ground around a station with different vegetation cover. In this case the use of group refraction coefficients is suggested in particular for points situated below 1100 m above sea level. This analysis is based on observations carried out on the Prlish region of Tatra Mountains.

INFLUENCE OF THE REFRACTION COEFFICIENT OF ELECTROMAGNETIC WAVES ON RESULTS OF MEASUREMENTS WITH ELECTROMAGNETIC RANGEFINDERS

Michal Knoll

1. Introduction

The phenomenon of refraction is important in geodesy whenever there is the case of precise measurements carried out with optical instruments (theodolit, leveller, electro-optic rangefinder).

Many authors dealt with the problem of refraction considering it from the viewpoint of geometrical optics. Such an approach is right if it can be assumed that the wavelength $\lambda = 0$. This assumption can be accepted in the range of visual radiation $\lambda = 0.4$-$0.76\ \mu m$. But we cannot make such an approximation for microwave rangefinders working on centimeter waves.

When a side is measured with two instruments we shall get, on the whole, two results. The ratio of these values is called the scale of the side.

In the last years, many measurements have been made using the microwave and optical rangefinders. The comparison of results between them reveals the occurrence of a systematic error of the scale. In the majority of cases, measurements in the optical spectrum give higher values of distance than

measurements in microwave range. The work /8/ gives results of measurements of two the same sides on two Polish experimental networks performed with the microwave and electrooptical rangefinders. A hypothesis is put forth about existance of a difference of scales. As a result of the analysis carried out it was established with 98% probability that there are no reasons to reject the accepted hypothesis.

An incorrect determination of distance with a rangefinder may be caused by: instability of electronic system, careless measurement, insufficient knowledge of the coefficient of refraction, and inappropriate comparation. A unit of length which is conferred upon the rangefinder during the comparation is transferred onto sides of triangulation network. It is assumed that this unit is preserved by electronic system of the instrument with accuracy not lower than 10^{-6}. If we assume, moreover, that the electronic system of rangefinder is efficient, and that the comparation and measurement were carried out properly, the only source of errors causing a systematic scale difference can be the refraction coefficient of electromagnetic waves determined with insufficient accuracy. We shall consider, therefore, the effect of various factors on values of refraction coefficient for light waves and microwaves.

2. Refraction coefficient in a dispersion medium for light waves

2.1. Refraction coefficient for standard air

A formula describing the coefficient of refraction for standard air was introduced in 1953 by B. Edlen on the basis of the equation of Cauchy and studies of Barrell and Sears /4/. Subsequently, studies in this field were published by Rank (1958), Svensson (1960), Peck (1962) and Erickson (1961), providing new information about dispersion of electromagnetic waves in air and in water vapor.

On the basis of the latest studies /5/ the dispersion formula for standard air has the form:

$$(n-1)10^8 = 8342{,}13 + 2406030(130-\sigma^2)^{-1} + 15997(38{,}9-\sigma^2)^{-1}, \tag{2.1}$$

where σ - wavenumber in vacuo in μm^{-1}.

2.2. Dependence of the refraction coefficient n on temperature t and pressure p

B. Edlen in reference /5/ introduces formula which gives dependence of n on t and p. He starts from the relation

$$(n-1)_{tp} = K_\lambda D_{tp} \tag{2.2}$$

where K_λ - a factor dependent on wavelength, and D_{tp} - a density factor dependent on temperature and pressure.

The proof is based on the basic Lorentz-Lorenz relation. The equation has the form:

$$(n-1)_{tp} = \frac{p(n-1)_s}{720,775} \frac{1+p(0,817-0,0133t)10^{-6}}{1+0,0036610t} \quad (2.3)$$

and can be substituted with the formula of Barrell and Sears of 1939, with accuracy of the determination of n of 1×10^{-8}:

$$(n-1)_{tp} = (n-1)_s \frac{0,00138823\,p}{1+0,003671\,t} \quad (2.4)$$

The substitution of formula (2.3) with ~~formula~~ (2.4) with the above given accuracy is valid if t lies within the range 5-30 ^{o}C, and p in the range 700-800 Tr.

2.3. Effect of the content of water vapor

Following Barrell and Sears /1/ we shall write:

$$(n-1)_{tpf} = \frac{K_\lambda (p-f)[1+\beta_t(p-f)]}{1+\alpha t} + \frac{K'_\lambda f(1+\beta'_t f)}{1+\alpha t}. \quad (2.5)$$

This equation can be transformed /8/, by neglecting expressions $f^2\beta_t$ as values of the order of 10^{-7} at the most, in order to obtain members dependent on humidity f and members independent on f. We shall get then an equation which provides effect of taking account of humidity on the accuracy of determination of refraction coefficient:

$$n_{tpf} - n_{tp} = -f \frac{K_\lambda(1+2\beta_t p) - K'_\lambda(1+\beta'_t f)}{1+\alpha t}. \quad (2.6)$$

Values K_λ and β_t refer to dry air, and values K'_λ and β'_t - to moist air. They are defined as follows:

$$K_\lambda = \frac{(n-1)_\lambda}{760}(1+15\alpha),$$

$$K'_\lambda = (31{,}59+0{,}2963\sigma^2)10^{-8},$$

$$\beta_t = (0{,}817-0{,}0133t)10^{-6},$$

$$\beta'_t = 27\times 10^{-6},$$

$$\alpha = \frac{1}{273{,}15}.$$

Equation (2.6) is well satisfied in the limits of spectrum 644.0-435.9 nm.

Recent studies of Erickson /6/ determined refraction of water vapor with greater accuracy and for a larger range of spectrum 644.0-361.1 nm. The equation as a function of wavelength has the form:

$$n_{tpf} - n_{tp} = -f(5{,}722-0{,}0457\sigma^2)10^{-8} \tag{2.7}$$

and is valid for conditions which do not diverge much from t = 20 °C, p = 760 Tr, f = 10 Tr.

2.4. Effect of the content of carbon dioxide

It is assumed that in the standard air the content of CO_2 is 0.0003 parts per unit of volume. This corresponds to partial pressure 0.23 Tr.

B. Edlen /4/ gives formula by means of which he calculated the refraction coefficient of air, containing x parts CO_2 per unit volume in relation to the standard air:

$$(n-1)_x = [1+0{,}540(x-0{,}0003)](n-1)_s. \tag{2.8}$$

The difference between refraction coefficients for CO_2 and for the standard air, as a function of wavelength, has the form:

$$n_{CO_2} - n_s = (14485 + 117{,}8\sigma^2)10^{-8} \quad (2.9)$$

Values calculated from the above formula, given by Edlen, agree with values reported by T. Masui /9/.

3. Refraction coefficient of microwaves

The vector of electrical displacement $\vec{D}$ is connected with the vector of potrntial $\vec{E}$ in a given medium through the formula:

$$\vec{D} = \varepsilon_a \vec{E}. \quad (3.1)$$

where ε_a - dielectric permeability of the medium.

In isotropic medium we can write:

$$D = \varepsilon_a E. \quad (3.2)$$

Making use of the dielectric permeability of vacuum ε_o and permeability of air ε_p , the equation (3.2) can be written:

$$D = \varepsilon_a E = \varepsilon_0 E + \varepsilon_p E,$$

$$\varepsilon_a = \varepsilon_0 + \varepsilon_p, \quad \frac{\varepsilon_a}{\varepsilon_0} = 1 + \frac{\varepsilon_p}{\varepsilon_0}.$$

Let us denote:

$$\frac{\varepsilon_a}{\varepsilon_0} = \varepsilon, \quad \frac{\varepsilon_p}{\varepsilon_0} = \varepsilon'_p.$$

The relative permeability of air can be written as the sum of permeabilities of dry air ε_s and water vapor ε_w:

$$\varepsilon = 1 + \varepsilon_s N_s + \varepsilon_w N_w, \tag{3.3}$$

where N - number of particles in unit of volume.

Particles of water vapor have a constant dipole moment. Its effect on the field will depend on temperature T. Moreover, an induction moment appears in the electromagnetic field. If we take this into account in (3.3) and if we substitute appropriate values for N_s and N_w, we get:

$$\varepsilon = 1 + \varepsilon_s \frac{p}{RT} + \frac{f}{RT}\left(\varepsilon_{wi} + \frac{\varepsilon_{wd}}{T}\right), \tag{3.4}$$

where ε_{wi} - a constant connected with induction moment, ε_{wd} - - a constant connected with dipole moment, p - pressure of dry air, f - partial pressure of water vapor. After transformation of (3.4) we obtain:

$$\varepsilon = 1 + \varepsilon_s R^{-1} \frac{p}{T} + \varepsilon_{wi} R^{-1} \frac{f}{T} + \varepsilon_{wd} R^{-1} \frac{f}{T^2}. \tag{3.5}$$

Utilizing the relation:

$$n = \sqrt{\varepsilon} = 1 + \frac{\varepsilon - 1}{2} + \ldots$$

we obtain:

$$n = 1 + \frac{\varepsilon_s R^{-1}}{2} \frac{p}{T} + \frac{\varepsilon_{wi} R^{-1}}{2} \frac{f}{T} + \frac{\varepsilon_{wd} R^{-1}}{2} \frac{f}{T^2}. \tag{3.6}$$

For radio waves we use usually a value called refraction indicator:

$$N = (n-1)10^6.$$

Introducing into (3.6) the constants:

$$A = \frac{\varepsilon_0 R^{-1}}{2}, \quad B = \frac{\varepsilon_{w1} R^{-1}}{2}, \quad C = \frac{\varepsilon_{w2} R^{-1}}{2}$$

we obtain:

$$N = A\frac{p}{T} + B\frac{f}{T} + C\frac{f}{T^2}. \tag{3.7}$$

In practice we meet often the relation:

$$N = A\frac{p}{T} + C\frac{f}{T^2}. \tag{3.8}$$

Constants A , B , C are determined experimentally.

Formulas (3.7) and (3.8) have not been deduced strictly. Most of all, the calculations do not take into account the fact that the dielectric permeability is a function of the frequency of field.

4. Analysis of equations describing the refraction coefficient

4.1. Formula for microwaves

Differentiating equation (3.7) with respect to T , p and f and substituting the values $A = 103.49$, $B = -17.23$, $C = 495822$, for conditions $f = 25$ Tr, $p = 760$ Tr, $T = 303\ ^{\circ}K$, we obtain:

$$\frac{dN}{dT} = -AT^{-2}p - BT^{-2}f + CT^{-3}f = -1{,}7432,$$
$$\frac{dN}{dp} = AT^{-1} = 0{,}3415,$$
$$\frac{dN}{df} = BT^{-1} + CT^{-2} = 5{,}3437.$$

Assuming errors in determination of the parameters of atmosphere to be $dT = 1\ ^{\circ}K$, $dp = 1$ Tr, $df = 1$ Tr, we obtain:

$$dN = 5.631 \times 10^{-6},$$

which gives the relative accuracy of determination of the length of side 1:177000.

4.2. Formula for light waves

Differentiating equation (2.5) with respect to t, p and f and substituting suitable values for conditions $f = 25$ Tr, $p = 760$ Tr, $t = 30\ ^{\circ}C$ we obtain:

$$\frac{dn}{dp} \approx \frac{K_\lambda}{1+\alpha t}(1+2p\beta_t-2f\beta_t) = 3{,}49\times 10^{-7},$$
$$\frac{dn}{df} \approx \frac{K'_\lambda}{1+\alpha t}(1+2f\beta'_t)+\frac{K_\lambda}{1+\alpha t}(2f\beta_t-1-2p\beta_t) = -7{,}54\times 10^{-8},$$
$$\frac{dn}{dt} \approx \{K_\lambda(p-f)[1+\beta_t(p-f)]+K'_\lambda f(1+\beta'_t f)\}\frac{\alpha}{(1+\alpha t)^2} = 8{,}69\times 10^{-7}.$$

Assuming errors in determination of the parameters of atmosphere to be $dt = 1\ ^{\circ}C$, $dp = 1$ Tr, $df = 1$ Tr, we obtain:

$$dn = 0.94 \times 10^{-6}$$

which gives the relative accuracy of determination of the length of side 1:1,064,000.

Table 1 compares relative errors of the measurement of the side with microwave and light (optical) rangefinders depending on values dp, df and dt.

In order to determine error caused by neglecting humidity when calculating the refraction coefficient for light waves we shall make use of the formula (2.6). For $t = 30\ ^{\circ}C$, $f = 25$ Tr, $p = 760$ Tr we obtain:

$$n_{tpf} - n_{tp} = -1.34 \times 10^{-6}.$$

From Erickson's formula (2.7) we have:

$$n_{tpf} - n_{tp} = -1.38 \times 10^{-6}.$$

The effect of CO_2 on the refraction coefficient can be determined on the basis of equations (2.8) or (2.9). If we assume ten times larger concentration of CO_2 than in the standard air, which is a very large value, both equations give numbers significant only at the seventh decimal point.

5. Concluding remarks

The dispersion of electromagnetic waves in atmosphere is caused by absorption and polarization π of molecules. Neither polarization nor dielectric constant depend on frequency ω if it does not exceed the value of 10^8 Hz. A sharp drop of value is observed in microwave region ($\omega = 10^9 - 10^{12}$ Hz).

For the wave frequency $\omega = 10^{13}$ Hz and higher - hence for light waves - the orientational polarization (connected with particles possessing permanent dipole moments) disappears, and also induced polarization partly disappears, and it is only electron polarization that remains, π_e /10/. The value of π_e does not differ much from that of molar refraction, which can be calculated from the Lorentz-Lorenz equation. For microwaves, therefore, this part of refraction will be important which is connected with orientational polarizability.

Van Vleck /12/,/13/ foresaw two absorption spectra for microwaves. One can observe these spectra for wavelength 1.35 cm /11/ (lines of water vapor between two rotational states) and wavelengths 4 mm and 6 mm /2/ (absorption of magnetic dipoles of O_2 molecules).

Lately, carrier frequencies of microwave rangefinders increased considerably and approached the resonance frequency of water vapor ($\lambda = 1.35$ cm); it can be assumed then that disturbances in dispersion are caused by phenomenon of

anomalous dispersion. This, in turn, may cause changes in frequency of the emitted and received waves by the rangefinder (Figure 1). A change of frequency means a shift of the maximum energy E into another part of the spectrum.

It appears desirable, therefore, to determine dispersional formulas for each model of the rangefinder.

A large influence upon the measurement results with microwave rangefinder can be exerted by the so called near-ground effect. This effect is a nonlinear dependence of the pressure of water vapor on height near the surface of earth. On the whole, the line of sight runs higher over the terrain in its middle part than at the end points. The averaging of humidity measured at the end points does not appear, therefore, justified /7/.

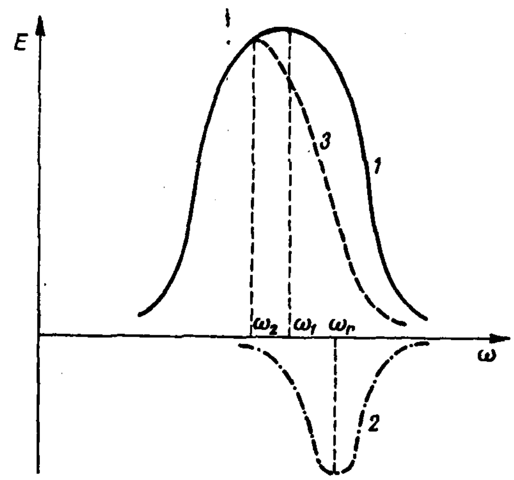
Measurements in the microwave region in industrial centers should be avoided. The pollution of atmosphere with chemical compounds, occurring there, may lead to anomalous dispersion.

It would appear also that the results of microwave measurements could be improved if the relation $\varepsilon = \varepsilon(\omega)$ was taken into account in formula (3.6). This relation could, in particular, change the value ε_{wd} in equation (3.4).

Table 1

dp [Tr]	df [Tr]	dt [deg]	(1) Dalmierz świetlny $\frac{ds}{s}$	(2) Dalmierz mikrofalowy $\frac{ds}{s}$
0,3	0,3	0,3	1:3 364 000	1:561 000
1	1	1	1:1 064 000	1:177 000
1	2	2	1:561 000	1:89 000
1	4	4	1:285 000	1:44 000
2	5	5	1:143 000	1:36 000

Key: (1) Light (optical) rangefinder; (2) Microwave rangefinder.



1 ———— frequency sent by rangefinder (max. E for ω_1)

2 —·—·—· resonance frequency (min. E for ω_r)

3 — — — — frequency received (max. E for ω_2)

Figure 1

REFERENCES

[1] Barrel H., Sears J. E., Phill. Trans. Roy. Soc. London, Ser. A, 1 (1939), 238.
[2] Beringer R., Phys. Rev. 70 (1946), 50.
[3] Bruhat G., *Cours de Physique Generale. Optique*, Paris 1947.
[4] Edlen B., J. Opt. Soc. Am. 43 (1953), 339.
[5] Edlen B., Metrologia 2.2 (1966), 71.
[6] Erickson K. E., J. Opt. Soc. Am. 52 (1962), 777, 781.
[7] Jones H. E., *Systematic errors in tellurometer and geodimeter measerements*, Geodetic survey of Canada, 1970.
[8] Knoll M., Narojczyk Z., *Wskaźnik refrakcji i zagadnienie skali sieci pomierzonej dalmierzami elektromagnetycznymi*. Praca dyplomowa magisterska, Politechnika Warszawska, 1977.
[9] Masui T., Rev. Opt. 46 (1957), 281.
[10] Pigoń K., Ruziewicz Z., *Chemia fizyczna*, Część III, Wrocływ 1976.
[11] Townes C. H., Merrit F. R.m, Phys. Rev. 70 (1946), 558.
[12] Van Vleck J. H., Phys. Rev. 71 (1947), 425.
[13] Van Vleck J. H., Phys. Rev. 71 (1947), 413.

Summary

There is an attempt of explanation of a phenomenon that exists in the form of systematic difference of scales consequent on microwave and electrooptical distance measurements. There is assumed that the essential factor causing this phenomenon is an allowance for refraction coefficient with insufficient accuracy. There is discussed the formulae for refraction coefficient in atmosphere in the two spectrum regions. For light waves there are considered the formulae by Edlen and Erickson and the formula by Barell and Sears that is so far applied to geodesy. There are pointed out some inaccuracies being consequent on deriving of the formulae for microwaves. There is also discussed the phenomenon of absorption in microwave region. It is proved that absorption has the essential influence on the systematic difference of scales.

INVESTIGATION OF THE INFLUENCE OF ERRORS OF JUNCTION POINTS ON THE ACCURACY OF ADJUSTED GEODETIC CONSTRUCTIONS

Jerzy Mialdun, Kazimierz Sikorski

1. Introduction

When adjusting geodetic networks it is assumed as a rule that the junction points are exact, without errors. This is dictated by the necessity of maintaining invariable coordinates in the existing catalogs. The necessity arises mainly from the adopted system of collecting and storing geodetic data.

At present, as the measurement techniques and the methods of treatment of measurement results continue to be developed, it occurs more and more frequently that networks of the lower orders are characterized by a higher internal accord than the supportive networks. The attachment of these lower-order sets to networks characterized by lower accuracy, with simultaneous assumption of the errorless nature of the points in connected networks, results in a considerable deformation of both the adjusted measurement results and coordinates of the new points, and of the estimate of their accuracy. The problem of adjustment with consideration of the effect of errors of junction points was treated among others in the works /1/ and /4/.

An interesting problem was considered in the work /2/. The author studied the effect of the errors of junction points

and of their placement on the accuracy of the newly determined points. He comes to the conclusion that when adjusting the number of points in newly established network it is necessary to limit the number to absolute necessity (about 3).

In the present work, studies on the effect of the number of junction points of connections are carried out under the assumption of the presence of errors and of the dependence between these points.

2. Construction of supportive network

In order to investigate the effect of connective points on errors of new established points we constructed a supportive network shown in Figure 1. The same Figure contains also ellipses of errors of the points in supportive network. In the construction of network we were guided by the following premises:

(a) the determined points are placed symmetrically with respect to points A, B which define the system,

(b) points of the supportive network are also symmetrical with respect to the points of connected network (consisting of four points Nos. 1, 2, 3, 4),

(c) all the constructions, both in the supportive and in connected network, consist of isosceles triangles,

(d) rejection of each pair of symmetrically placed junction points causes reduction of the number of measurement results by the same value.

The same accuracy of angular measurements was adopted in adjustment of supportive network and connected network. At the same time it was assumed that angular measurements were done from each determined (defined) point to all connective points lying on the same side of the axis of symmetry as the determined (defined) point.

3. Adjustment of supportive network and connected network

The supportive network was adjusted by an indirect method, determining the matrix of covariance of point coordinates in the form

$$\mathrm{Cov}(X) = (A^T A)^{-1}.$$

It was assumed during the adjusting that the elements of both supportive and connected network were determined with the same accuracy.

Investigation of the effect of errors was carried out in two groups A and B and six variants in each group. The supportive (determined) points in each group were the same.

In the group of variants A it was assumed that the junction points were errorless and independent of each other; in the group B - that there were errors and mutual dependence.

Two or four pairs of points lying symmetrically with respect to the connected network were rejected (omitted) in each variant, causing the same change in error equations in appropriate variants.

For junction points in both groups of variants we took:

Variant 1	101, 102, 103, 104
Variant 2	101, 102, 103, 104, 105, 106, 107, 108
Variant 3	101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112
Variant 4	105, 106, 107, 108
Variant 5	105, 106, 107, 108, 109, 110, 111, 112
Variant 6	109, 110, 111, 112

The adjustment and the analysis of accuracy were performed on the basis of an algorithm presented in /3/, determining values of the weight coefficients of the points of network. Moreover, the following values were also determined:

$$Sp(Q^{-1}) \text{ for } q_{sr} = \sqrt{\frac{Sp(Q^{-1})}{n}},$$

where q_{sr} - average value of the weight coefficient of a mean arbitrary point of network, Q^{-1} - covariance matrix, n - number of points of the network.

The results of adjustment of the supportive network are presented in Table 1.

Conclusions

The analysis of adjustment results allows us to state that in the considered network, both in the variant group A and B, an increase of the number of supportive points improves only little the accuracy of placement of the new points.

This conclusion agrees with that in the work /2/.

The attachment of a new network to supportive points, assumed to be errorless (variant A), lying at a considerable distance from the new points and, at the same time, characterized by a low accuracy, worsens considerably the accuracy of placement of the new connected points.

In the case when we do not assume the errorless character of the connected points (variant B), the accuracy of new points also worsens but to a considerably smaller degree.

As a result of joint adjustment of coordinates of the points of supportive and connected networks, one obtains an improvement in the accuracy of location of the points in supportive network by about 10%, on the average.

The considered case, however, deals with too small a network to justify generalization of conclusions. Further investigations are required, and they will be carried out by the authors.

Table 1. Supportive network.

Nr punktu	$\sqrt{q_{xx}}$	$\sqrt{q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$
101	0,145	0,145	0,205
102	0,103	0,103	0,145
103	0,145	0,145	0,205
104	0,103	0,103	0,145
105	0,308	0,308	0,435
106	0,229	0,229	0,324
107	0,308	0,308	0,435
108	0,229	0,229	0,324
109	0,513	0,513	0,726
110	0,410	0,410	0,580
111	0,513	0,513	0,726
112	0,410	0,410	0,580

$Sp(Q^{-1}) = 2{,}441, \quad q_{\delta t} = 0{,}451.$

Results of adjustment of the connected network are shown in Tables 2, 3, 4.

Table 2. Adjustment results of a new network, with the assumption of errorles character and independence of coordinates of the points in supportive network.

Nr punktu	WARIANT A1	WARIANT A2	WARIANT A3	WARIANT A4	WARIANT A5	WARIANT A6
	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$
1	0,145	0,139	0,139	0,833	0,790	2,766
2	0,188	0,179	0,177	0,927	0,872	2,913
3	0,145	0,139	0,139	0,833	0,790	2,766
4	0,188	0,179	0,177	0,924	0,872	2,913

Table 3. Adjustment results of a new network, with the assumption of the presence of errors and of dependence of coordinates of the points in supportive network.

Nr punktu	WARIANT B1	WARIANT B2	WARIANT B3	WARIANT B4	WARIANT B5	WARIANT B6
	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$	$\sqrt{q_{xx}+q_{yy}}$
1	0 173	0,169	0,168	0,236	0,233	0,372
2	0,125	0,207	0,206	0,280	0,274	0,418
3	0,173	0,169	0,168	0,236	0,233	0,372
4	0,215	0,207	0,206	0,280	0,274	0,418
101	0,201	0,201	0,200			
102	0,141	0,141	0,141			
103	0,201	0,201	0,200			
104	0,141	0,141	0,141			
105		0,417	0,416	0,417	0,415	
106		0,314	0,314	0,306	0,305	
107		0,417	0,416	0,417	0,415	
108		0,314	0,314	0,306	0,305	
109			0,680		0,699	0,643
110			0,550		0,558	0,508
111			0,680		0,699	0,643
112			0,550		0,558	0,508

Table 4. Average value of the mean arbitrary weight coefficient of the network q_π and trace of matrix of the adjusted system.

WARIANT		1	2	3	4	5	6
(1) Sieć dowiązywania q_π	A	0,168	0,160	0,159	0,881	0,832	2,840
po wyrównaniu $Sp(Q^{-1})$		0,113	0,103	0,101	3,106	2,769	32,273
(1) Sieć dowiązywana q_π	B	0,195	0,189	0,188	0,259	0,254	0,325
po wyrównaniu $Sp(Q^{-1})$		0,152	0,143	0,141	0,268	0,259	0,423
(2) Sieć modelowa q_π	A	0,178	0,299	0,451	0,383	0,538	0,657
przed wyrównaniem $Sp(Q^{-1})$		0,126	0,714	2,441	0,588	2,315	1,727
(3) Sieć modelowa q_π	B	0,174	0,288	0,427	0,366	0,516	0,579
po wyrównaniu $Sp(Q^{-1})$		0,121	0,666	2,193	0,535	2,130	1,343

Key: (1) Connected network after adjustment; (2) Model network before adjustment; (3) Model network after adjustment.

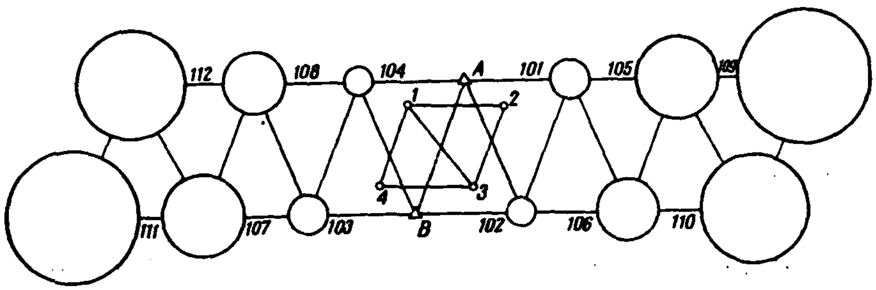


Figure 1

REFERENCES

[1] Hausbrandt S., *Wyrównanie sieci trygonometrycznych z odrzuceniem założenia bezbłędności punktów dowiązania*, Geodezja i Kartografia, T III, z. 1, 1954.

[2] Latoś St., *Investigations on settlement of density of Nodal Points on the accuracy of Detailed Networks*. Zeszyty Naukowe AGH, Nr 38, Kraków, 1975.

[3] Sikorski K., *Wyrównanie sieci triangulacyjnych z odrzuceniem bezbłędności punktów nawiązania*. Geodezja i Kartografia, Rocznik XX, Nr 3, 1970.

[4] Zlatanow G., *Średni błąd funkcji wielkości wyrównanych metodą najmniejszych kwadratów z uwzględnieniem błędów danych wyjściowych i zależności między nimi*. Przegląd Naukowo-techn. AGH, Nr 3, seria G, z. 7, 1964 r.

Summary

This paper discusses an influence of junction points errors on the accuracy of connected network. Investigations have been carried out in the two groups of variants: with the assumption of errorlessness of junction points (A variants) and with allowance for erroneousness and dependence of those points (B variants).

Resulting these analyses it has been determined, that increasing of a number of junction points influences very small on increasing of the accuracy of adjusted network and that junction to distant points makes worse the accuracy of connected network as well.

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